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NONINTERCEPTIVE TECHNIQUES FOR THE MEASUREMENT OF LONGITUDINAL PARAMETERS FOR INTENSE H^- BEAMS*

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Summary

With increasing brightness, beam diagnostic techniques requiring interception of the beam become impractical. For H^- particle beams, solutions for this problem based on the phenomenon of photodissociation are currently under investigation at the Los Alamos National Laboratory accelerator test stand (ATS). A laser can be used to selectively neutralize portions of the beam that can be characterized after the charged particles have been swept away. We have used this technique for the measurement of current density versus longitudinal phase and the longitudinal phase-space distribution at the output of the ATS radio-frequency quadrupole (RFQ). The results of our measurement are compared with the predictions of the particle-dynamics code, PARMTEQ.

Introduction

For H^- particle beams, the phenomenon of photodissociation can be exploited to selectively tag specific spatial and/or temporal components of the beam profile for characterization. A laser beam is used to selectively neutralize a segment of the particle beam, and the H^0 particles are subsequently segregated from the H^- beam at a beam-deflection element. The beam parameters at the point of neutralization are then simply reconstructed by using only the drift distance for the neutralized portion of the particle beam. In principle, this technique can be used to reconstruct the full six-dimensional phase-space density distribution by altering the spatial and/or temporal structure of the photon field transversing the particle beam and by using the appropriate detector geometry. Figure 1 shows configurations appropriate to measurements of transverse and longitudinal components of the beam. Provided the spatial and temporal dimensions of the photon field are sufficiently small compared to the particle-beam structure, information is available at the micropulse level, allowing investigation of micropulse variations within the macrostructure. For beams of high brightness, this technique has the advantage of being noninterceptive. Charge build-up and ionization at slits and collectors that intercept the beam can affect measured beam parameters. Additionally, emissions from surfaces exposed to the beam compromise the vacuum, which will generally affect system performance. With sufficient beam intensity, interceptive sensors are damaged or destroyed. Likewise, because no apertures or alterations of the operating environment are required, this technique can be considered nonintrusive to the extent that the number of particles removed from the beam remains small. Nonintrusive, noninterceptive monitoring of the transverse parameters for high-current beams has been accomplished[1] by observation of interactions with residual gases over a length of the beam; however, such procedures may not be appropriate if space-charge effects are nonnegligible.

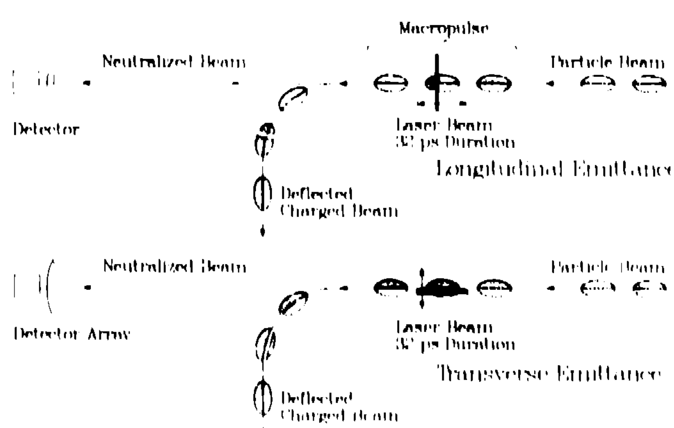

Fig. 1. Configurations appropriate to measurement of transverse and longitudinal components of the beam using the laser-induced neutralization diagnostics approach. For purposes of illustration, three bunches comprise the beam macrostructure.

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Experimental Technique

The laser-induced neutralization diagnostics approach (LINDA) is currently being evaluated at the Los Alamos ATS. We have used this technique for measuring current density versus longitudinal phase and the longitudinal phase-space distributions for the ATS RFQ. The experimental setup is shown in Fig. 2. A single transverse slice of the microstructure is neutralized with a 1.06-μm Nd:YAG mode-locked laser capable of output energies of up to 10 mJ for a single 32-ps pulse. A telescope and cylindrical lens are used to expand the laser beam to 7 mm in the transverse dimension and to a focus of less than 30 μm in the longitudinal dimension at the point of intersection with the particle beam, 5.7 cm from the output of the RFQ. The neutralization fraction for the portion of the H^- beam illuminated by the laser pulse can be estimated by considering a field of photons uniformly distributed in the transverse plane such that the probability for photodissociation is

$$P(z) = \int dz\,dt\ (1 - \exp[-\sigma(\nu)\chi(z,t)t])\ \tau(z,t) \quad ,$$

where $\sigma(\nu)$ is the cross section for photodissociation at an energy $h\nu$, and the photon density as a function of the longitudinal dimension and time $\chi(z,t)$ is assumed for simplicity to be

$$\chi(z,t) = \begin{cases} \chi_0 & z_0 \le z \le z_1 \quad t_0 \le t \le t_1 \\ 0 & \text{otherwise} \end{cases} \quad .$$

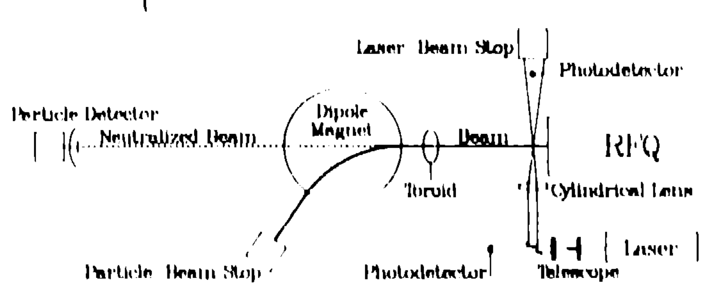

Fig. 2. Experimental setup used for the measurement of current density versus longitudinal phase and the longitudinal phase space distribution at the ATS.

The function $\tau(z,t)$ is the particle longitudinal trajectory. Figure 3 plots the probability of neutralization for a 1-mJ pulse versus the longitudinal dimension illuminated by the laser. At this power level and with a laser beam that illuminates less than 0.2 mm of the H^- beam's longitudinal dimension, the probability of neutralization is near unity. Also, in this region, 10% variation in the laser power has a negligible effect, and reflections below the 1% level can be ignored.

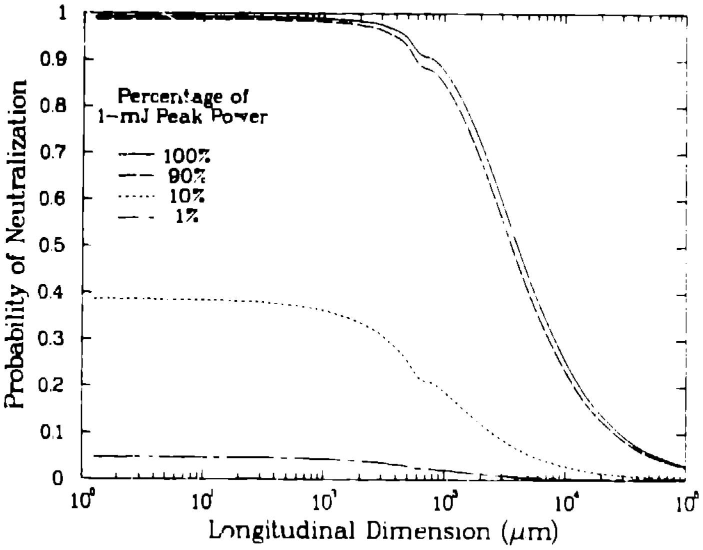

Fig. 3. Probability of neutralization for the particle beam versus the longitudinal dimension illuminated by the 1-mJ, 32-ps, 1.06-μm laser pulse.

The time at which the laser fires can be controlled only to within a few microseconds; therefore, the 413-MHz RFQ phase is random with respect to the time when the laser pulse traverses the particle beam. The relative phase for the sampled portion of the beam is determined by a computer-interfaced interval timer having approximately 15-ps resolution. An InP:Fe photodetector, having a rise time of less than 100 ps, is positioned in the laser beam downstream from the interaction point (see Fig. 2) and is used to provide the start for the interval timer. The negative-going zero-crossing point of the potential as measured near the end of the RFQ tank is used for the interval-timer end point. System temporal resolution is estimated to be approximately 30 ps. To ensure laser, ion-source, and RFQ stability during data acquisition, additional electronics are included to veto events for which the laser power, source current, or RFQ power fall below a predetermined discrimination level.

For longitudinal density measurements, the neutral-particle detection system consists of a subnanosecond secondary-emissions monitor (SEM) with an active area of 5.1 cm^2, a 450-MHz, 105X amplifier, and a gated, charge-integrating analog-to-digital converter providing interface to the computer. For the longitudinal phase-space measurements, the amplified SEM waveform is digitized rather than integrated. A second InP:Fe photodetector in the laser beam initiates data acquisition so that time-of-flight information can be taken from the digitized waveform. A temporal dispersion in the 32 ps sample of the particle beam is produced by a 7.57-m drift between the point of neutralization and the SEM. Although this dispersion obviates the use of multigigahertz detection apparatus, less than 5% of the neutralized portion of the particle beam is collected. Figure 4 shows an example of the digitized waveform observed at the SEM output.

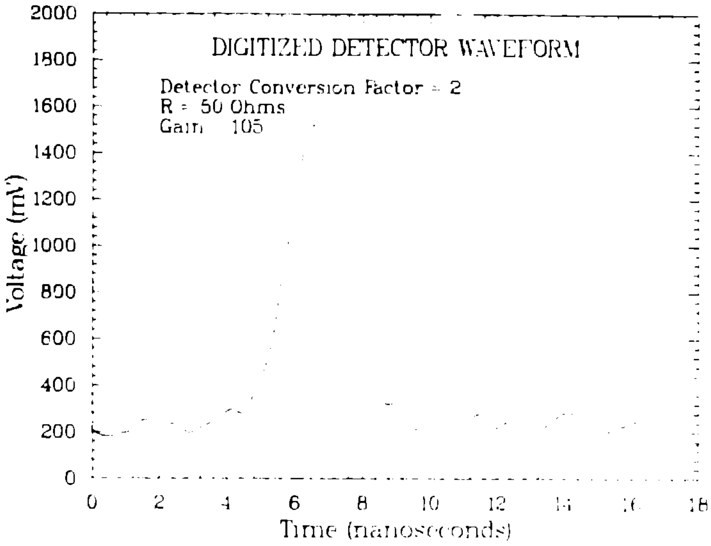

Fig. 4. Digitized sample of the amplified waveform observed at the output of the SEM.

Results

Results of the current density versus longitudinal phase for RFQ power levels at phase-stable acceleration, near acceleration threshold, and below threshold are shown in Fig. 5. These results indicate a 50° FWHM current-density distribution for the H^- beam bunch for a phase-stable accelerated beam compared to approximately 25° for the PARMTEQ[2] calculations. (PARMTEQ calculations represent the density distribution at the end of the RFQ and exclude all particles with energy less than 95% of the central energy.) Near acceleration threshold, the bunch is broadened and becomes skewed toward larger phase angles. Below threshold, only background is observed from the 10-ns integration of the neutral particles generated by the 100-keV ion source. The structure in the data toward higher phase angles is the result of reflection of the laser beam from a defective vacuum exit window.

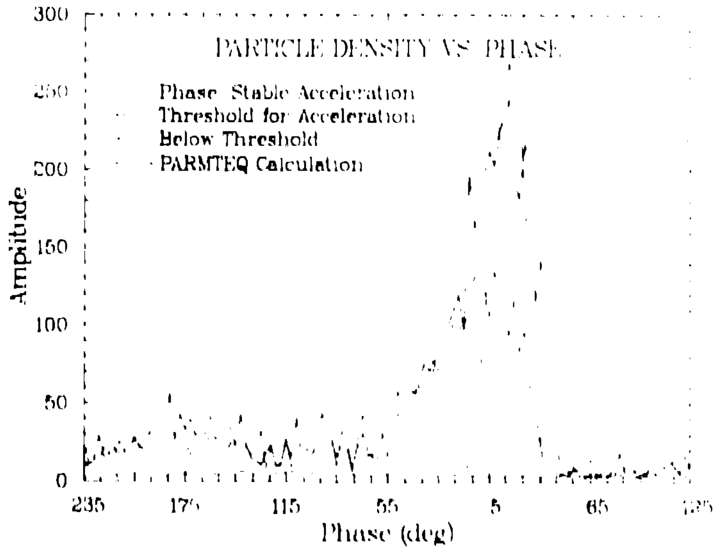

Fig. 5. Particle density versus the RFQ phase angle for RFQ power levels sufficient for phase-stable acceleration, at acceleration threshold, and below threshold. PARMTEQ calculations are indicated by the chain dot curve.

The longitudinal phase-space distribution (Fig. 6) indicates that within the region of the beam bunch, the centroids of the energy distributions are constant, but that at larger phase angles the energy falls off rapidly. The approximately 2-ns pulse width (Fig. 4) indicates a 1% dispersion in energy for the RFQ output and was consistent over the full range of phase angles. Although we are viewing only a small transverse segment of the neutralized beam, PARMTEQ calculations indicate that the longitudinal parameters measured near the center of the transverse distribution are indicative of those for the whole beam.

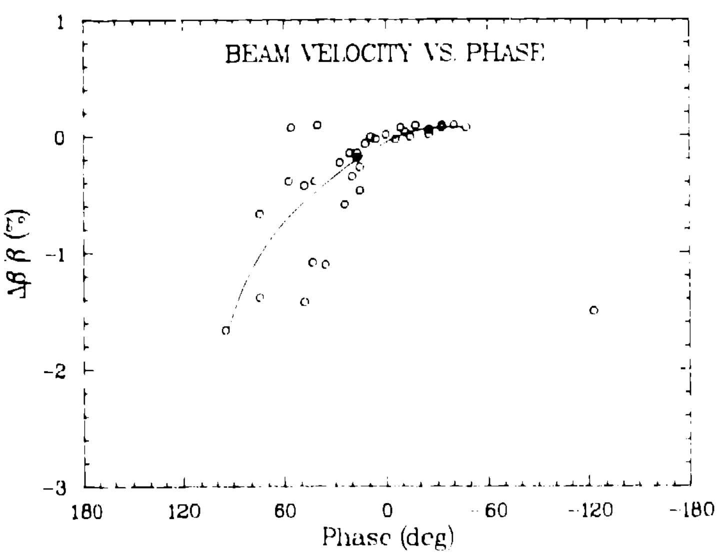

Fig. 6. Centroid of particle-beam velocity distribution versus RFQ phase angle. The curve is merely to guide the eye.

Conclusions

The present measurements indicate the feasibility of LINDA and the type of information that can be obtained for longitudinal phase-space measurements. We have not yet obtained adequate stability of the laser output nor have we optimized the interval timing apparatus. We must develop an appropriate method for discrimination of the neutral-particle background from the ion source. We plan to develop a multigigahertz neutral-particle detection system that will allow a shorter drift length and, consequently, will allow collection of most of the neutralized beam. We also are preparing to use this technique to measure the transverse components of the ATS RFQ beam.

The problems involved with diagnostics of intense particle beams are becoming acute for the ATS. Simultaneously, we have a need for more detailed diagnostics to assist in our pursuit of low-emittance, intense particle beams. For our H^- particle beam, LINDA appears to be an attractive method that avoids the problems associated with interceptive diagnostic techniques, allows measurement of both longitudinal and transverse parameters, cannot be confounded by space-charge effects, and provides for data acquisition at the micropulse level.

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